

Durham Research Online

Deposited in DRO:

21 May 2018

Version of attached file:

Published Version

Peer-review status of attached file:

Peer-reviewed

Citation for published item:

Hastings, Janna and Mains, Abraham and Artal-Sanz, Marta and Bergmann, Sven and Braeckman, Bart P. and Bundy, Jake and Cabreiro, Filipe and Dobson, Paul and Ebert, Paul and Hattwell, Jake and Hefzi, Hooman and Houtkooper, Riekelt H. and Jelier, Rob and Joshi, Chintan and Kothamachu, Varun B. and Lewis, Nathan and Lourenço, Artur Bastos and Nie, Yu and Norvaisas, Povilas and Pearce, Juliette and Riccio, Cristian and Rodriguez, Nicolas and Santermans, Toon and Scarcia, Pasquale and Schirra, Horst Joachim and Sheng, Ming and Smith, Reuben and Suriyalaksh, Manusnan and Towbin, Benjamin and Tuli, Mary Ann and van Weeghel, Michel and Weinkove, David and Zečić, Aleksandra and Zimmermann, Johannes and le Novère, Nicolas and Kaleta, Christoph and Witting, Michael and Casanueva, Olivia (2017) 'WormJam : a consensus C. elegans metabolic reconstruction and metabolomics community and workshop series.', *Worm.*, 6 (2). e1373939.

Further information on publisher's website:

<https://doi.org/10.1080/21624054.2017.1373939>

Publisher's copyright statement:

© 2017 The Author(s). Published with license by Taylor Francis© Janna Hastings, Abraham Mains, Marta Artal-Sanz, Sven Bergmann, Bart P. Braeckman, Jake Bundy, Filipe Cabreiro, Paul Dobson, Paul Ebert, Jake Hattwell, Hooman Hefzi, Riekelt H. Houtkooper, Rob Jelier, Chintan Joshi, Varun B. Kothamachu, Nathan Lewis, Artur Bastos Lourenço, Yu Nie, Povilas Norvaisas, Juliette Pearce, Cristian Riccio, Nicolas Rodriguez, Toon Santermans, Pasquale Scarcia, Horst Joachim Schirra, Ming Sheng, Reuben Smith, Manusnan Suriyalaksh, Benjamin Towbin, Mary Ann Tuli, Michel van Weeghel, David Weinkove, Aleksandra Zecic, Johannes Zimmermann, Nicolas le Novère, Christoph Kaleta, Michael Witting, and Olivia Casanueva This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Additional information:

Use policy

The full-text may be used and/or reproduced, and given to third parties in any format or medium, without prior permission or charge, for personal research or study, educational, or not-for-profit purposes provided that:

- a full bibliographic reference is made to the original source
- a [link](#) is made to the metadata record in DRO
- the full-text is not changed in any way

The full-text must not be sold in any format or medium without the formal permission of the copyright holders.

Please consult the [full DRO policy](#) for further details.

Durham University Library, Stockton Road, Durham DH1 3LY, United Kingdom
Tel : +44 (0)191 334 3042 | Fax : +44 (0)191 334 2971
<https://dro.dur.ac.uk>



WormJam: A consensus C. elegans Metabolic Reconstruction and Metabolomics Community and Workshop Series

Janna Hastings, Abraham Mains, Marta Artal-Sanz, Sven Bergmann, Bart P. Braeckman, Jake Bundy, Filipe Cabreiro, Paul Dobson, Paul Ebert, Jake Hattwell, Hooman Hefzi, Riekelt H. Houtkooper, Rob Jelier, Chintan Joshi, Varun B. Kothamachu, Nathan Lewis, Artur Bastos Lourenço, Yu Nie, Povilas Norvaisas, Juliette Pearce, Cristian Riccio, Nicolas Rodriguez, Toon Santermans, Pasquale Scarcia, Horst Joachim Schirra, Ming Sheng, Reuben Smith, Manusnan Suriyalaksh, Benjamin Towbin, Mary Ann Tuli, Michel van Weeghel, David Weinkove, Aleksandra Zečić, Johannes Zimmermann, Nicolas le Novère, Christoph Kaleta, Michael Witting & Olivia Casanueva

To cite this article: Janna Hastings, Abraham Mains, Marta Artal-Sanz, Sven Bergmann, Bart P. Braeckman, Jake Bundy, Filipe Cabreiro, Paul Dobson, Paul Ebert, Jake Hattwell, Hooman Hefzi, Riekelt H. Houtkooper, Rob Jelier, Chintan Joshi, Varun B. Kothamachu, Nathan Lewis, Artur Bastos Lourenço, Yu Nie, Povilas Norvaisas, Juliette Pearce, Cristian Riccio, Nicolas Rodriguez, Toon Santermans, Pasquale Scarcia, Horst Joachim Schirra, Ming Sheng, Reuben Smith, Manusnan Suriyalaksh, Benjamin Towbin, Mary Ann Tuli, Michel van Weeghel, David Weinkove, Aleksandra Zečić, Johannes Zimmermann, Nicolas le Novère, Christoph Kaleta, Michael Witting & Olivia Casanueva (2017) WormJam: A consensus C. elegans Metabolic Reconstruction and Metabolomics Community and Workshop Series, *Worm*, 6:2, e1373939, DOI: [10.1080/21624054.2017.1373939](https://doi.org/10.1080/21624054.2017.1373939)

To link to this article: <https://doi.org/10.1080/21624054.2017.1373939>



© 2017 The Author(s). Published with license by Taylor & Francis© Janna Hastings, Abraham Mains, Marta Artal-Sanz, Sven Bergmann, Bart P. Braeckman, Jake Bundy, Filipe Cabreiro, Paul Dobson, Paul Ebert, Jake Hattwell, Hooman Hefzi, Riekelt H. Houtkooper, Rob Jelier, Chintan Joshi, Varun B. Kothamachu, Nathan Lewis, Artur Bastos Lourenço, Yu Nie, Povilas Norvaisas, Juliette Pearce, Cristian Riccio, Nicolas Rodriguez, Toon Santermans, Pasquale Scarcia, Horst Joachim Schirra, Ming Sheng, Reuben Smith, Manusnan Suriyalaksh, Benjamin Towbin, Mary Ann Tuli, Michel van Weeghel, David Weinkove, Aleksandra Zecic, Johannes Zimmermann, Nicolas le Novère, Christoph Kaleta, Michael Witting, and Olivia Casanueva



Accepted author version posted online: 06
Sep 2017.
Published online: 06 Sep 2017.



Submit your article to this journal [↗](#)



Article views: 237



View related articles [↗](#)



View Crossmark data [↗](#)

MEETING REPORT



WormJam: A consensus *C. elegans* Metabolic Reconstruction and Metabolomics Community and Workshop Series

Janna Hastings^a, Abraham Mains^a, Marta Artal-Sanz^b, Sven Bergmann^c, Bart P. Braeckman^d, Jake Bundy^{Id}^e, Filipe Cabreiro^f, Paul Dobson^g, Paul Ebert^h, Jake Hattwellⁱ, Hooman Hefzi^j, Riekelt H. Houtkooper^k, Rob Jelier^l, Chintan Joshi^m, Varun B. Kothamachuⁿ, Nathan Lewis^m, Artur Bastos Lourenço^b, Yu Nie^o, Povilas Norvaisas^f, Juliette Pearce^a, Cristian Riccio^p, Nicolas Rodriguezⁿ, Toon Santermans^l, Pasquale Scarcia^q, Horst Joachim Schirraⁱ, Ming Sheng^r, Reuben Smith^k, Manusnan Suriyalaksh^a, Benjamin Towbin^s, Mary Ann Tuli^t, Michel van Weeghel^a, David Weinkove^u, Aleksandra Zečić^c, Johannes Zimmermann^v, Nicolas le Novèreⁿ, Christoph Kaleta^v, Michael Witting^w, and Olivia Casanueva^a

^aEpigenetics, Babraham Institute, Babraham Research Campus, Cambridge, UK; ^bDevelopmental Biology, Andalusian Center for Developmental Biology, Consejo Superior de Investigaciones Científicas/Junta de Andalucía/Universidad Pablo de Olavide, Seville, Spain; ^cComputational Biology, University of Lausanne, Lausanne, Switzerland; ^dDepartment of Biology, University of Gent, Gent, Belgium; ^eComputational and Systems Medicine, Imperial College London, London, UK; ^fStructural and Molecular Biology, University College London, London, UK; ^gSchool of Computer Science, University of Manchester, Manchester, UK; ^hSchool of Biological Sciences, University of Queensland, Queensland, Australia; ⁱCentre for Advanced Imaging, University of Queensland, Queensland, Australia; ^jDepartment of Bioengineering, Novo Nordisk Center for Biosustainability at UC San Diego, University of California, San Diego, USA; ^kLaboratory Genetic Metabolic Diseases, Academic Medical Center, Amsterdam, Netherlands; ^lCentre of Microbial and Plant Genetics, KU Leuven, Leuven, Belgium; ^mDepartment of Pediatrics, Novo Nordisk Center for Biosustainability at UC San Diego, University of California, San Diego, USA; ⁿSignalling, Babraham Institute, Babraham Research Campus, Cambridge, UK; ^oSchool of Human and Life Sciences, Canterbury Christ Church University, Canterbury, UK; ^pSanger Institute, University of Cambridge, Cambridge, UK; ^qDep. Biosciences Biotechnologies Biopharmaceutics, University of Bari, Bari, Italy; ^rNeurobiology, MRC LMB, Cambridge, UK; ^sFriedrich Miescher Institute, Basel, Switzerland; ^tWormBase, Caltech, Pasadena, CA, USA; ^uDepartment of Biosciences, Durham University, Durham, UK; ^vMedical Systems Biology, Christian-Albrechts-University Kiel, Kiel, Germany; ^wResearch Unit Analytical BioGeoChemistry, Helmholtz Zentrum Muenchen, Muenchen, Germany

ARTICLE HISTORY Received 21 August 2017; Accepted 25 August 2017

Introduction

A GENiE (EU COST action, www.worm-genie.eu) workshop was held at the Babraham Institute in Cambridge, UK on April 19 and 20, 2017, to discuss global challenges around *Caenorhabditis elegans* metabolic reconstructions and metabolomics (<http://www.babraham.ac.uk/genie-workshop>). This short report describes the outcomes from that workshop, notably the initiation of a global community to collaboratively discover and describe the metabolism of *C. elegans*.

C. elegans is a well established workhorse for research in both fundamental biology and medicine, with applications including developmental biology, ageing-associated research and the elucidation of pathomechanisms of diseases.¹ Powerful molecular as well as genetic tools, ease of cultivation, short generation times and a considerable overlap in its

fundamental biology with higher organisms, make *C. elegans* an ideal object of study. In recent years, metabolism is increasingly recognised as an important contributor to *C. elegans* healthspan and lifespan, as well as the basis of adaptation to different environments.^{2,3} Most of the historical efforts to detect changes in metabolism have been based on molecular tools including gene expression and/or reporter strains. Despite its importance for a large number of research applications, efforts to reconstruct the global map of *C. elegans* metabolism only started recently, notably with the publication of two independent constraint-based metabolic models last year^{4,5} (although automated reconstructions from pathway databases were produced before.⁶) Such whole-genome metabolic reconstructions are a key ingredient for a large

CONTACT Janna Hastings  janna.hastings@babraham.ac.uk  Babraham Institute, Babraham Research Campus, Babraham, Cambridge, CB22 3AT, UK.

© 2017 Janna Hastings, Abraham Mains, Marta Artal-Sanz, Sven Bergmann, Bart P. Braeckman, Jake Bundy, Filipe Cabreiro, Paul Dobson, Paul Ebert, Jake Hattwell, Hooman Hefzi, Riekelt H. Houtkooper, Rob Jelier, Chintan Joshi, Varun B. Kothamachu, Nathan Lewis, Artur Bastos Lourenço, Yu Nie, Povilas Norvaisas, Juliette Pearce, Cristian Riccio, Nicolas Rodriguez, Toon Santermans, Pasquale Scarcia, Horst Joachim Schirra, Ming Sheng, Reuben Smith, Manusnan Suriyalaksh, Benjamin Towbin, Mary Ann Tuli, Michel van Weeghel, David Weinkove, Aleksandra Zecic, Johannes Zimmermann, Nicolas le Novère, Christoph Kaleta, Michael Witting, and Olivia Casanueva. Published with license by Taylor & Francis.

This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

number of applications including the integration of diverse -omics datasets, investigation of disease-associated changes in metabolism, studying the responses to nutritional interventions, identifying gene-environment interactions, and elucidating inter-organismal interactions on the metabolic level at both physiological and evolutionary timescales.⁷ The reconstruction of *C. elegans* metabolism thus promises to open up the extensive toolbox of constraint-based modelling for *C. elegans* research.

Creation and expansion of a consensus reconstruction for *C. elegans* metabolism research

During the workshop, ongoing efforts were identified that are merging and reconciling the two published models mentioned above, as well as other unpublished models developed in different labs (<http://cai-gsmodel.cai.uq.edu.au>),⁸ into consensus reconstructions. The models are partially overlapping and far from complete; many metabolites that can be identified and quantified in *C. elegans* are not represented. Furthermore, the existing models are currently distributed across different databases and web portals. Users wishing to update or extend these models have no provision for merging their changes into any other version, including the original. Ongoing reconciliations between different models are hindered by the lack of agreement on shared standards for the annotation of molecules and reactions.⁹ There is thus an urgent need to agree on standards and a central location for hosting, editing and version management of a master community-wide *C. elegans* reconstruction. This will form the basis for a community effort to expand the consensus model to yet uncovered metabolic pathways relevant in the manifold aspects of *C. elegans* research.

Metabolomics data and a community driven effort are required to fill the gaps in reconstructions

The documented metabolome of *C. elegans* encompasses around 1,000 metabolites, while the estimated full metabolome may be in the order of >10,000 molecules, based on experiences gathered across different metabolomics labs. Among these molecules, lipids and secondary metabolites are particularly poorly covered. A curation effort based on metabolomics data is under way within WormBase (<http://www.wormbase.org/search/molecule/WBMol%3A>), but this daunting task requires a dedicated community-driven effort to cover

the vast quantity of under-annotated metabolites as well as expert knowledge on the different analytical technologies (NMR and MS) employed to evaluate the quality of the metabolite annotation. Rigorous validation of the experimental approaches in metabolomics and hence curation of data quality is of the utmost importance. Also, even considering only the documented metabolome, there is an overlap of only up to 50% with the current models. A specific example of pathway misrepresentation is that of sphingolipid synthesis, essential for *C. elegans* postembryonic development.¹⁰ While it is known that in *C. elegans* C17iso-sphingosine is synthesized as sphingoid base from mono-methyl branched chain fatty acid (C15iso),¹¹ the published models use palmitic acid instead. Therefore, manual curation and expert knowledge of metabolic pathways is essential to build models that provide accurate predictions.

The challenges of building metabolic reconstructions for multicellular organisms

Besides the number of metabolites that require further revision, metabolic reconstructions of multicellular organisms are challenging for other reasons. Firstly, tissue-specific differences in metabolic pathways necessitate the long-term goal of generating tissue-specific models. Secondly, recent research suggests that there is a profound impact of the environment on the worm's physiology. In particular, the choice of bacteria as food source, and whether it is provided alive or dead, has a vast impact on metabolism and life history traits.^{12,13} Ongoing efforts in the reconstruction of joint models of *C. elegans* along with its live *E. coli* food source as well as with bacteria that are natural colonizers of the *C. elegans* gut will be required to disentangle bacterial from worm-specific metabolic effects of experimental perturbations. Finally, the peptone-based media that is used to grow bacteria influences both experimental reproducibility and metabolism, calling for a revision of standard worm culture methods to include chemically-defined media.¹⁴ A consensus metabolic model will allow the prediction of an optimal growth medium, and should therefore be a key ingredient in these efforts.

WormJam: an open community vision for the future

To achieve these aims, WormJam (short for *Worm Jamboree*) is being established as a platform for a community effort towards reconciliation of existing and

expansion of the unified *C. elegans* metabolic reconstruction. With the increasing recognition of metabolism as being of pivotal importance for ageing, development, disease mechanisms as well as evolution, the availability of a community-driven consensus reconstruction of *C. elegans* metabolism will lay the foundation for bringing *C. elegans* to the forefront of metabolism research.

As part of this effort, our objectives for the next 12 months within the WormJam community are:

- Ensuring all existing *C. elegans* metabolic reconstructions and partial consensus reconstructions are freely accessible online.
- Annotation of all molecules that can be identified with confidence in *C. elegans* targeted metabolomics experiments across participating metabolomics labs within the WormBase Molecule resource.
- Establishment of a platform for community curation of the metabolic reconstructions and creation of a consensus *C. elegans* metabolic network. The reconstruction will be tightly integrated with WormBase as a central hub of *C. elegans* data resources.
- Holding annotation jamboree workshops targeting missing *C. elegans* specific pathways and metabolites, the first of which will be held in November 2017 (<https://www.helmholtz-muenchen.de/genie-workshop-2017/index.html>).
- We are seeking contributors from all aspects of *C. elegans* biology. Please join the discussion at <https://groups.google.com/forum/#!forum/wormjam>.

Disclosure of potential conflicts of interest

No potential conflicts of interest were disclosed.

Funding

The workshop was generously funded by the EU GENIE COST network BM1408, with additional support from the Babraham Institute (BBSRC/KEC).

ORCID

Jake Bundy  <http://orcid.org/0000-0002-1164-8465>

References

- [1] Corsi AK, Wightman B, Chalfie M. A transparent window into biology: A primer on *Caenorhabditis elegans*. Genetics. 2015;200(2):387-407. doi:10.1534/genetics.115.176099. PMID:26088431
- [2] Lemieux GA, Ashrafi K. Investigating connections between metabolism, longevity, and behavior in *Caenorhabditis elegans*. Trends Endocrinol Metab. 2016;27(8):586-96. doi:10.1016/j.tem.2016.05.004. PMID:27289335
- [3] Sommer RJ, Ogawa A. Hormone signaling and phenotypic plasticity in nematode development and evolution. Curr Biol. 2011;21(18):R758-66. PMID:21959166 doi:10.1016/j.cub.2011.06.034
- [4] Gebauer J, Gentsch C, Mansfeld J, Schmeißer K, Waschina S, Brandes S, Klimmasch L, Zamboni N, Zarse K, Schuster S, et al. A genome-scale database and reconstruction of *Caenorhabditis elegans* metabolism. Cell Syst. 2016;2(5), 312-22. doi:10.1016/j.cels.2016.04.017. PMID:27211858
- [5] Yilmaz LS, Walhout AJM. A *Caenorhabditis elegans* genome-scale metabolic network model., Cell Syst. 2016;2(5):297-311. doi:10.1016/j.cels.2016.04.012. PMID:27211857
- [6] Büchel F, Rodriguez N, Swainston N, Wrzodek C, Czaundera T, Keller R, Mittag F, Schubert M, Glont M, Golebiewski M, et al. Path2Models: large-scale generation of computational models from biochemical pathway maps. BMC Syst Biol. 2013;7:116. doi:10.1186/1752-0509-7-116. PMID:24180668
- [7] Lewis NE, Nagarajan H, Palsson BO. Constraining the metabolic genotype-phenotype relationship using a phylogeny of *in silico* methods. Nat Rev Microbiol. 2012;10(4):291-305. PMID:22367118
- [8] Ma L, Chan AHC, Hattwell J, Ebert PR, Schirra HJ. Systems biology analysis using a genome-scale metabolic model shows that phosphine triggers global metabolic suppression in a resistant strain of *C. elegans*. BiorXiv preprint. 2017; 144386. doi: <https://doi.org/10.1101/144386>
- [9] Ebrahim A, Almaas E, Bauer E, Bordbar A, Burgard AP, Chang RL, Dräger A, Famili I, Feist AM, Fleming RM, et al. Do genome-scale models need exact solvers or clearer standards? Mol Syst Biol. 2015;11(10):831. doi:10.15252/msb.20156157. PMID:26467284
- [10] Zhu, H, Shen, H, Sewell, AK, Kniazeva, M, Han, M. (2013) A novel sphingolipid-TORC1 pathway critically promotes postembryonic development in *Caenorhabditis elegans*. eLife. 2013;2:e00429.
- [11] Chitwood DJ, Lusby WR, Thompson MJ, Kochansky JP, Howarth OW. The glycosylceramides of the nematode *Caenorhabditis elegans* contain an unusual, branched-chain sphingoid base. Lipids. 1995;30(6):567-73. doi:10.1007/BF02537032. PMID:7651085
- [12] Zhang J, Holdorf AD, and Walhout AJ. *C. elegans* and its bacterial diet as a model for systems-level understanding of host-microbiota interactions. Curr Opin Biotechnol. 2017;46:74-80. doi:10.1016/j.copbio.2017.01.008. PMID:28189107
- [13] Gao, AW, Chatzispyrou, IA, Kamble, R, Liu YJ, Herzog K, Smith RL, van Lenthe H, Vervaart MAT, van

Cruchten A, Luyf AC, et al., (accepted for publication, 2017) A sensitive mass spectrometry platform identifies metabolic changes of life history traits in *C. elegans*. Scientific Reports Scientific Reports 7, e2408. doi:10.1038/s41598-017-02539-w.

[14] Virk B., Jia J, Maynard CA, Raimundo A, Lefebvre J, Richards SA, Chetina N, Liang Y, Helliwell N, Cipinska M, et al. Folate acts in *E. Coli* to accelerate *C. elegans* aging independently of bacterial biosynthesis. Cell Reports. 2016;14(7) 1611-1620. doi:10.1016/j.celrep.2016.01.051.PMID:26876180